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Highly efficient near lossless video compression using selective intra prediction for HEVC lossless mode

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ABSTRACT

Lossless coding mode of high efficiency video coding (HEVC) relies on efficient intra prediction methods for achieving higher compression. Sample based angular intra prediction (SAP) is a modification proposed for the conventional block-based intra prediction (BP) in the HEVC standard. In this paper a selective intra prediction (SIP) algorithm is proposed for lossless intra mode coding within HEVC, which uses an adaptive switching strategy between the two intra prediction methods, BP and modified SAP (MSAP), on a per pixel basis. MSAP is a modification proposed in this work to improve the prediction accuracy of SAP. The proposed SIP algorithm is a near lossless algorithm that selects the best prediction for each pixel to reduce the residual energy thereby increasing the coding efficiency. To circumvent the huge overhead required for the transmission of the selection from encoder to decoder, SIP adopts piggybacking the selection on the least-significant-bit (LSB) of the transmitted residual for each pixel. The proposed approach removes overhead at the expense of a ± 1 reconstruction error for each pixel which is negligible for 8-bit or 10-bit input videos. Experimental results show significant coding gains for the proposed SIP over the HEVC anchor and similar state-of-the-art lossless coding algorithms.

1. Introduction

The joint venture by the ITU-T video coding experts group (VCEG) and ISO/IEC moving picture experts group (MPEG), called joint collaborative team on video coding (JCT-VC), developed the most recent video compression standard, high efficiency video coding (HEVC) [1]. Evolution of most of the popular video coding standards are highly associated with the works of the premier video coding standardization organizations ITU-T and ISO/IEC [2,3]. Joint standards developed by these two pioneers extensively use video-processing functions for the capture, transmission and display of video sequences for almost all day-to-day video coding applications like multimedia messaging, video streaming over internet, SD and HD TV and video conferencing [4]. HEVC, the successor of popular H.264 video compression standard [5], targets the new era of ultra high resolution videos with higher frame rates [6]. Creative refinement of existing tools in conjunction with enhanced capabilities for parallel processing accounts for the higher compression efficiency of HEVC over its ancestors.

The proposed work concentrates on the improvement of intra coding stage of HEVC standard. In HEVC, all the pixels inside each prediction unit (PU) use the same intra prediction angle and a fixed reference row for the intra prediction process. The reference row is created from the neighbouring reconstructed blocks and hence the prediction accuracy decreases as we move off from the reference row in vertical or horizontal directions. In lossless coding mode, the reconstructed samples lying above or to the left of the current pixel are available for prediction process. Thus, prediction can be performed row wise or column wise from a pair of pixels lying above or to the left of the current pixel. SAP [7–9] follows this strategy for better intra prediction accuracy. During the prediction of boundary samples inside a PU, SAP suffers zero angle prediction error and to mitigate the same, this paper proposes MSAP. However, due to image peculiarities, this technique may result in higher residual energy for a few number of pixels inside each PU when compared with BP that exists in HEVC anchor model. Although the number of such pixels are relatively less, the analysis shows that the percentage of such pixels which favour BP varies across different classes of test sequences. Effective utilization of this behaviour of pixels for the reduction of residual energy is done in SIP by adopting BP for those pixels which favour it while retaining the MSAP for rest. This process may create immense overhead, since the selection of prediction method is done at pixel level and not at the block level. To circumvent this overhead, selective intra prediction (SIP) employs a per-pixel adaptive switching by piggybacking the selection on LSB of the transmitted residual for each pixel.

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The proposed SIP assures the utilization of the best prediction among BP and MSAP for each pixel to achieve higher efficiency at the expense of LSB changes. In the proposed method, the LSB of the prediction residual conveys the information regarding the choice of prediction to the decoder for the decoding process. In the process of adjusting the LSBs of MSAP and BP, reconstructed pixels undergo a ±1 change in their values. Since the pixels are represented using either 8-bits or 10-bits, visual impact of LSB change is almost nil. Above all, when the input video is 8 bit and the profile is main 10, the compression is perfectly lossless as the pixel values are always even.

The rest of this paper is organized as follows. Section 2 provides an overview of HEVC lossless mode and the BP process in HEVC anchor model. Section 3 covers the related work SAP and MSAP in brief. Section 4 presents the proposed SIP method in detail. The residual analysis that led to the development of SIP is also explained in Section 4. The experimental results and their analysis are provided in Section 5. Section 6 provides the conclusions of the work.

2. Overview of HEVC

HEVC, like most of the earlier video compression standards, follow the popular block-based hybrid video coding scheme. In HEVC, intra and inter predictions are extensively used to exploit the data dependency within and across frames for the minimization of residual energy. Transform coding of the prediction residuals [10,11], ensure the convergence of energy to a few coefficients which is followed by an efficient entropy coding stage that use CABAC (Context based adaptive binary arithmetic coding). A unified effect of all the individual stages ensures the best compression efficiency for the HEVC encoder.

2.1. Lossless coding in HEVC

Transform, quantization and all the in-loop filtering operations that comprise deblocking filter (DF), sample adaptive offset (SAO) and adaptive loop filter (ALF) are bypassed in HEVC lossless mode [12]. Hence, the efficiency of the intra prediction becomes very critical for this mode as the prediction residuals are directly fed to the entropy encoder. Two flags, specified in the configuration settings of the profiles, decide the choice of lossless coding either at the frame level or at the CU level. The first flag in the picture parameter set (PPS) indicates whether lossless coding is enabled at the frame level. If this flag is set, the second flag attains its significance and indicates whether lossless coding is enabled at CU level or not. If the first flag is in the reset condition, further transmission of flags at CU level is not required as lossless coding is disabled at frame level itself. To activate lossless coding for each and every CU, both flags should be set to 1.

2.2. Intra prediction in HEVC

Intra prediction modes of HEVC is a super set of the intra prediction modes of its ancestor H.264/AVC. The available set of 9 prediction modes in H.264 is extended to 35 in HEVC that comprise dc and planar modes besides the 33 angular prediction modes [13,14]. Linear interpolation at an accuracy of 1/32 is applied to the selected pair of pixels to raise the accuracy of the prediction process. For the BP adopted in HEVC, samples for prediction are selected from neighbouring reconstructed blocks for the formation of two arrays called the main array and the side array. When the prediction direction is vertical, the main array is the array that contains the samples lying above the current CU while the side array contains samples lying to the left of the current CU. For horizontal prediction, the left array is the main array while the side array is formed from the neighbouring samples above the current CU [15]. The prediction direction can be negative or positive for both vertical and horizontal prediction modes. Samples selected from the main array alone are used for the prediction process when the prediction direction is positive in both vertical and horizontal modes. For negative prediction angles, the main array is extended by including samples from the side array. The extended main reference row is solely used for the selection of the reference samples in the prediction process.

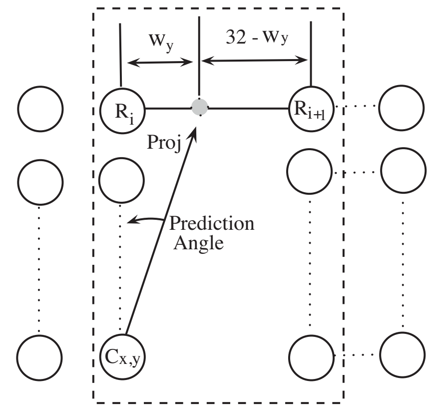

Fig. 1. Projection to reference row in block prediction.

For the prediction of the current sample $C_{x,y}$ in angular modes, its location is projected to the reference row of pixels to obtain R_i and R_{i+1}, by applying the selected prediction direction as shown in Fig. 1. The region enclosed in thick dotted lines in Fig. 1 represents the enlarged region to increase the clarity of understanding. Variables x and y specify the co-ordinates of the current pixel $C_{x,y}$. The displacement d, signalled at an accuracy of 1/32 pixel, associated with the selected intra prediction mode is used for the calculation of pixel shifts at integer levels (c_y) for the reference pair, reference sample index (i) and weighing parameter (w_y) as given in (1)–(3). Value of w_y, computed using (3), determines the exact location where the projection may fall between the reference pair.

$$c_y = (y \cdot d) \gg 5 \tag{1}$$

$$i = (x + c_y) \tag{2}$$

$$w_y = (y \cdot d)\&31 \tag{3}$$

After the selection of reference samples R_i and R_{i+1}, interpolation at an accuracy of 1/32 is performed across the selected pair of pixels as given in (4) [13]. If horizontal prediction modes are used, y in (1)–(4) should be replaced by x.

$$C_{x,y} = ((32 - w_y) \cdot R_i + w_y \cdot R_{i+1} + 16) \gg 5 \tag{4}$$

3. Related work

In HEVC, all the pixels inside a PU use the same fixed reference row for the prediction process. But in lossless coding mode, pixels within the PU and just above or to the left of the current row or column are available for the prediction process. SAP is a sample based prediction techniques that exploit this factor for higher prediction accuracy.

3.1. Sample based angular intra prediction (SAP)

In SAP [7–9] the reference samples are selected from adjacent rows or columns based on prediction direction to predict the current sample as shown in Fig. 2. After the selection of reference samples, SAP follows the same linear interpolation in BP. When the reference sample falls outside the current PU, reconstructed boundary samples B_1, B_2 and B_3 are extended to form samples E_1, E_2 and